Orthotropic material homogenization of composite materials including damping

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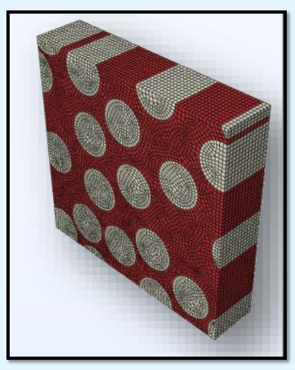
Introduction

In the multiscale analysis of composite materials obtaining the effective equivalent material properties of the composite from the properties of its constituents is an important bridge between different scales. Although, a variety of homogenization methods are already in use, there is still a need for further development of novel approaches which can deal with complexities such as frequency dependency of material properties; which is specially of importance when dealing with damped structures.

Time-domain methods

Material homogenization is performed in two separate steps: a static step and a dynamic one.

Static analysis → Apply strain on RVE → Calculate averaged stress tensor → Use Hook's law to obtain homogenized properties

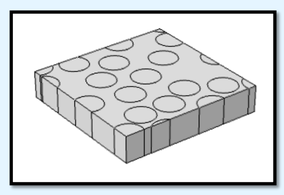


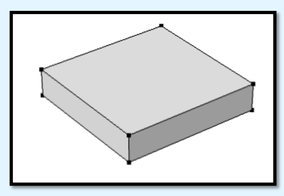
Dynamic analysis → Use homogenized properties → Stress, strain and strain rates in the RVE → Obtain damping parameters

Frequency-domain method

Wave dispersion based homogenization is performed to provide homogenized damping and material properties in a single step.

Create FE model of the RVE → Wave dispersion analysis → Fit orthotropic analytical models on the RVE results → Homogenized orthotropic material and damping properties



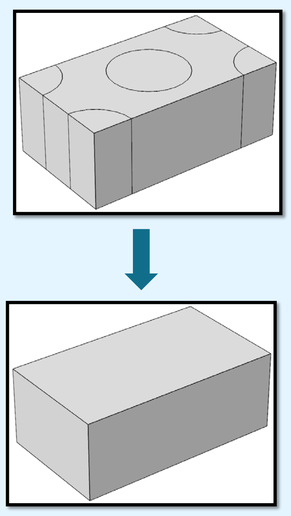


Numerical results

Starting from the known material properties of the constituents and the detailed geometry of the RVE, homogenized orthotropic material properties and viscous damping coefficients of the composite are obtained.

Material properties	Matrix	Fiber
E [GPa]	72.4	2.76
ν [-]	0.2	0.35
ρ [kg/m^3]	2500	1500
Loss factor	0.015	0.0018

Fiber volume fraction = 40%



Material properties	Time-domain	Frequency-domain
E_{xx} [GPa]	6.052	6.069
E_{yy} [GPa]	6.050	6.069
E_{zz} [GPa]	30.574	30.636
ν_{xy}	0.459	0.4594
ν_{xz}	0.0558	0.0556
ν_{yz}	0.0558	0.0556
G_{xy} [GPa]	2.077	2.079
G_{xz} [GPa]	2.240	2.243
G_{yz} [GPa]	2.240	2.243

Damping parameters	Time-domain	Frequency-domain
η_{11}[MPa.s]	0.0202	0.0205
η_{12}[MPa.s]	0.0096	0.0098
η_{13}[MPa.s]	0.0081	0.0086
η_{22}[MPa.s]	0.0197	0.0192
η_{23}[MPa.s]	0.0081	0.0083
η_{33}[MPa.s]	0.0163	0.0170
η_{44}[MPa.s]	0.0047	0.0044
η_{55}[MPa.s]	0.0050	0.0050
η_{66}[MPa.s]	0.0050	0.0050

Aspects	Time-domain method	Frequency-domain method
Steps	2 steps: 1 Static step and 1 dynamic one (-)	1 Dynamic step More consistent (+)
Undamped formulation	Real Faster FE solution (+)	Complex Slower FE solution (-)
Damped formulation	Complex Higher effort vs. undamped (-)	Complex No extra effort vs. undamped (+)
Directions	3 – (Typically related to principle directions) (-)	> 3 – (Better representation of fiber distribution) (+)

Conclusions

- Novel time and frequency domain orthotropic material homogenization methods are developed.
- The methods use static/dynamic behavior of micro-scale RVE to provide macro-scale homogenized properties.
- Existing methods are extended to include damping homogenization.
- Comparison of the results of different methods show a promising agreement between these methods.

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